Evaluation of 157nm Substrate Damage During Mask Repair

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Outline:

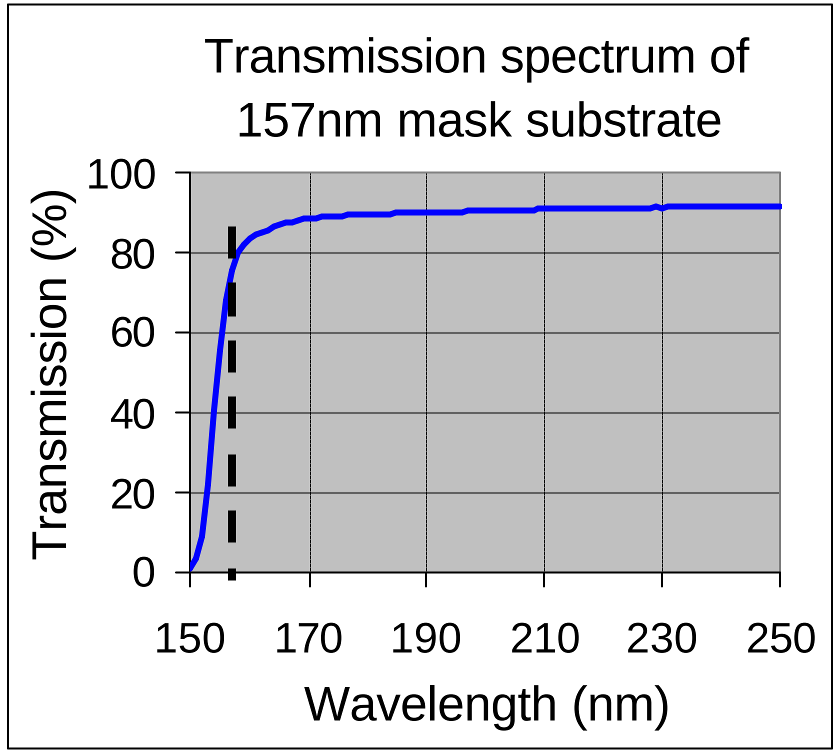
- Introduction - Key challenges in mask repair
- Evaluation of 157nm substrate damage during repair
  - Experimental set up
  - Results
- Comparison with other low damage repair alternatives
- Summary

Key issues in FIB mask repair

- Focused Ga ion beam (FIB) based repair is approaching its fundamental limits
  - Even the low Ga ion dose used in defect search and imaging can cause unacceptable transmission loss (Ga stain).
  - Difficult to manage ‘river-bed’ and ‘over-scan’ effect in tight features
- Surface charging hinders edge placement precision

Specific issues in 157nm mask repair

- Fused silica substrate:
  - 157nm near absorption edge
  - Expected high sensitivity to Ga stain and organic contamination in repair



- Ga stain:
  - Ga ion projected range is about 40-60nm under repair conditions
  - Removing this layer would create a 60-90º phase defect

Evaluation of substrate damage during repair

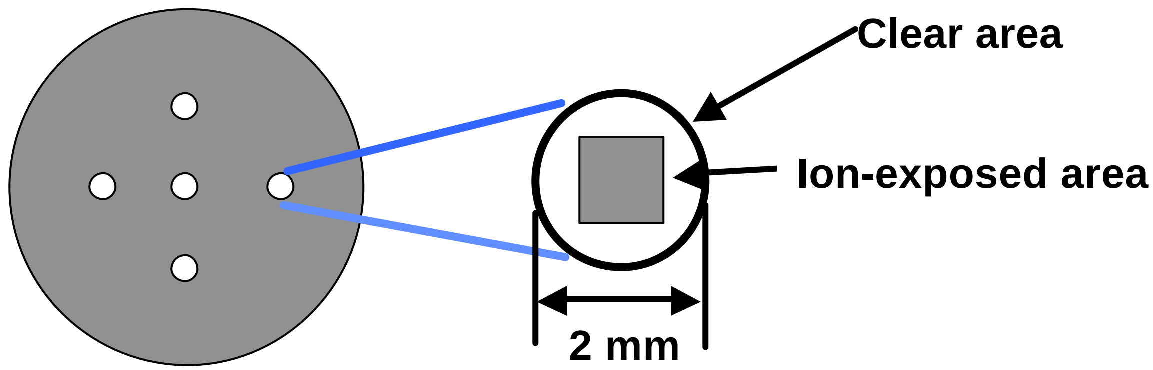
- Motivation:
  - How will Ga ion FIB repair affect 157nm transmission?
- Metrology limits:
  - Resist is not yet adequate for defect printability studies
  - No AIMS tool available for transmission measurement
- Instead, we perform direct measurements of substrate damage:
  - Assess Ga stain impact on 157nm transmission
  - Evaluate other alternative sources: Kr-ion, e-beam

Intel/FEI/MIT-LL experiments

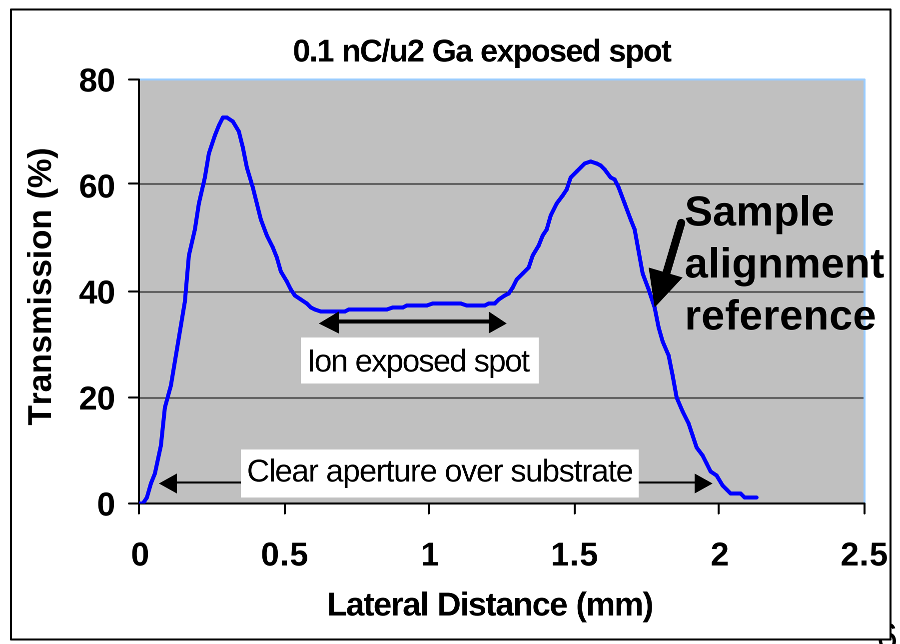
- Substrate material: ¼" thick, 1" dia. disk (T~75% @157nm)
- Exposure conditions on 1mm x1mm area:
  - 30kV Ga ions, 30kV Kr ions and 1kV electron beam
  - Two exposure doses:
    - Low dose (0.01nC/μ^2) – Received by substrate during defect search and imaging
    - High dose (0.1nC /μ^2) – Partial dose received by substrate during repair
- Post-exposure treatment and measurement:
  - 172nm photon + O_2 clean and transmission measurement on VUV-visible spectrometer @ MIT-LL
  - Surface roughness measurement
  - Wet acid post-clean

Pinhole transmission measurement

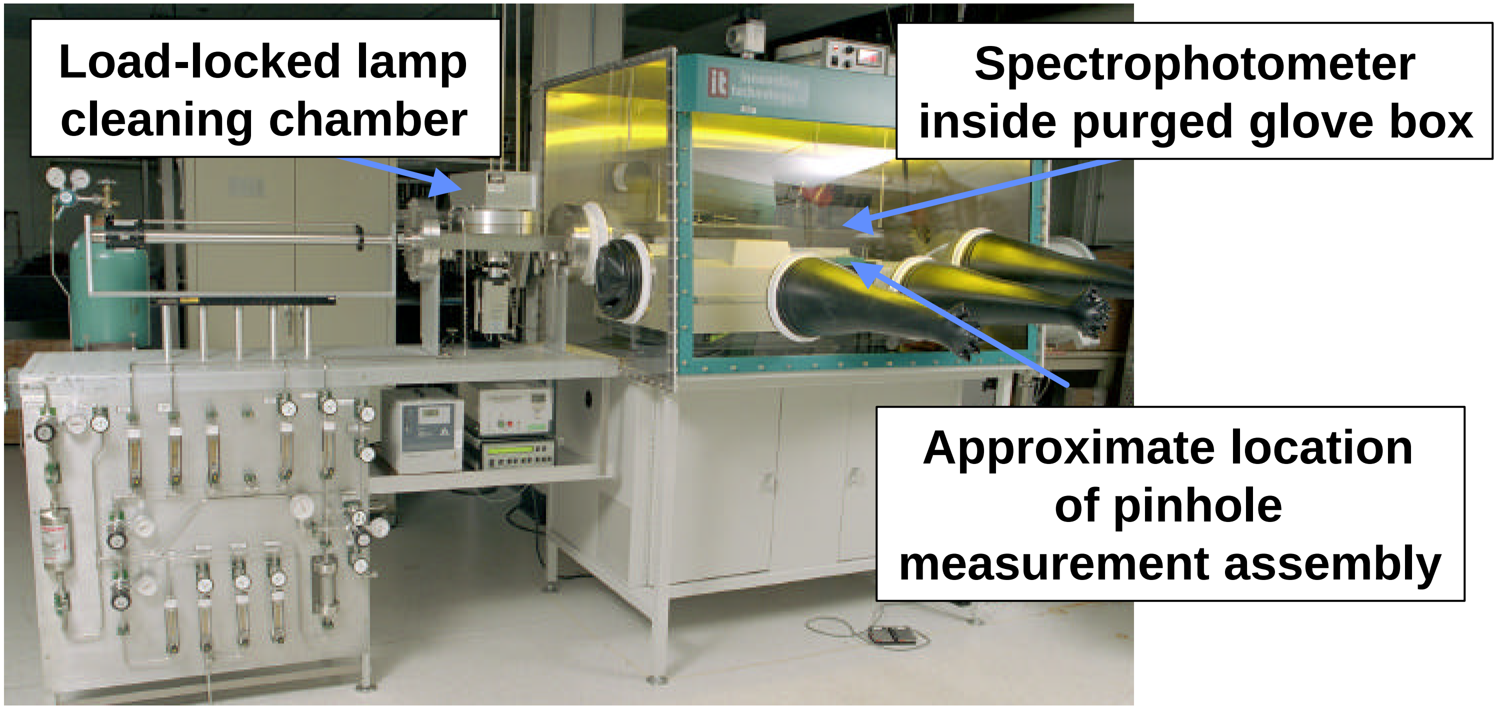
- Overlay template for locating exposed area on substrate



- Apertured spectrometer:
  - 250 µm spatial resolution
  - 0.2% repeatability error

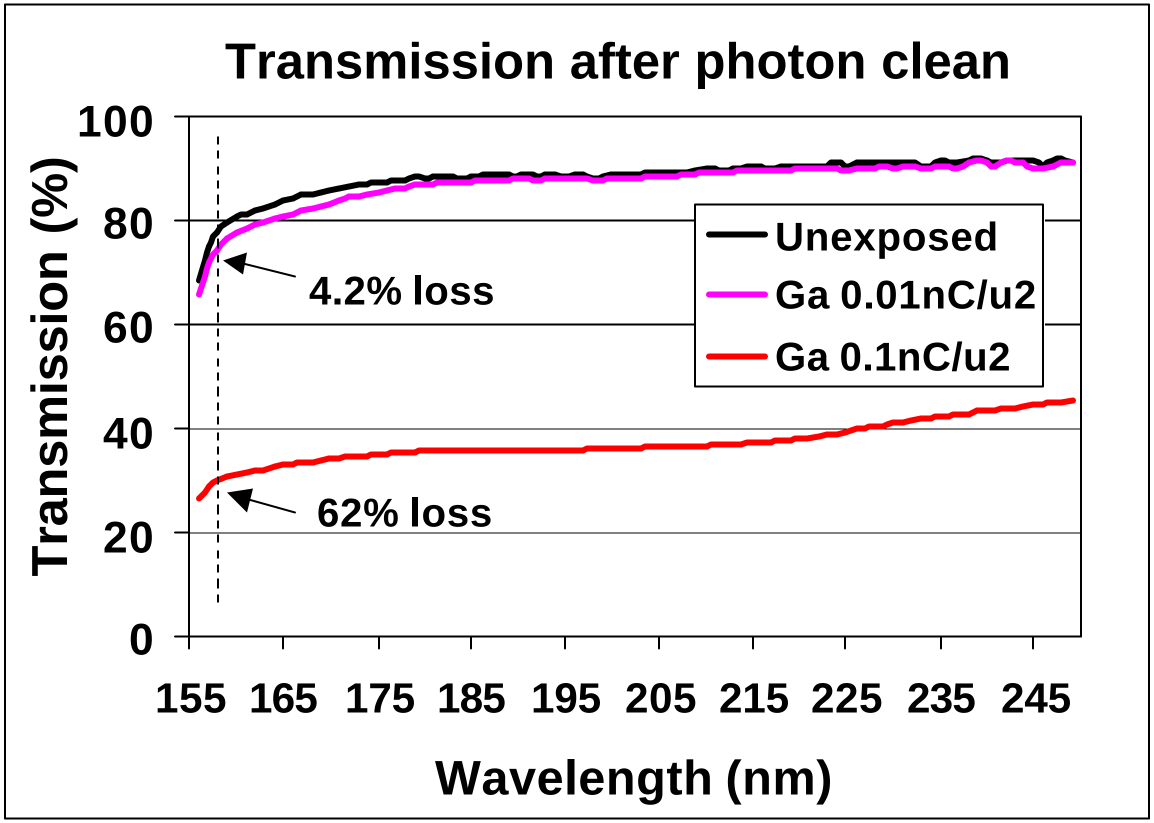


Spectrometer system



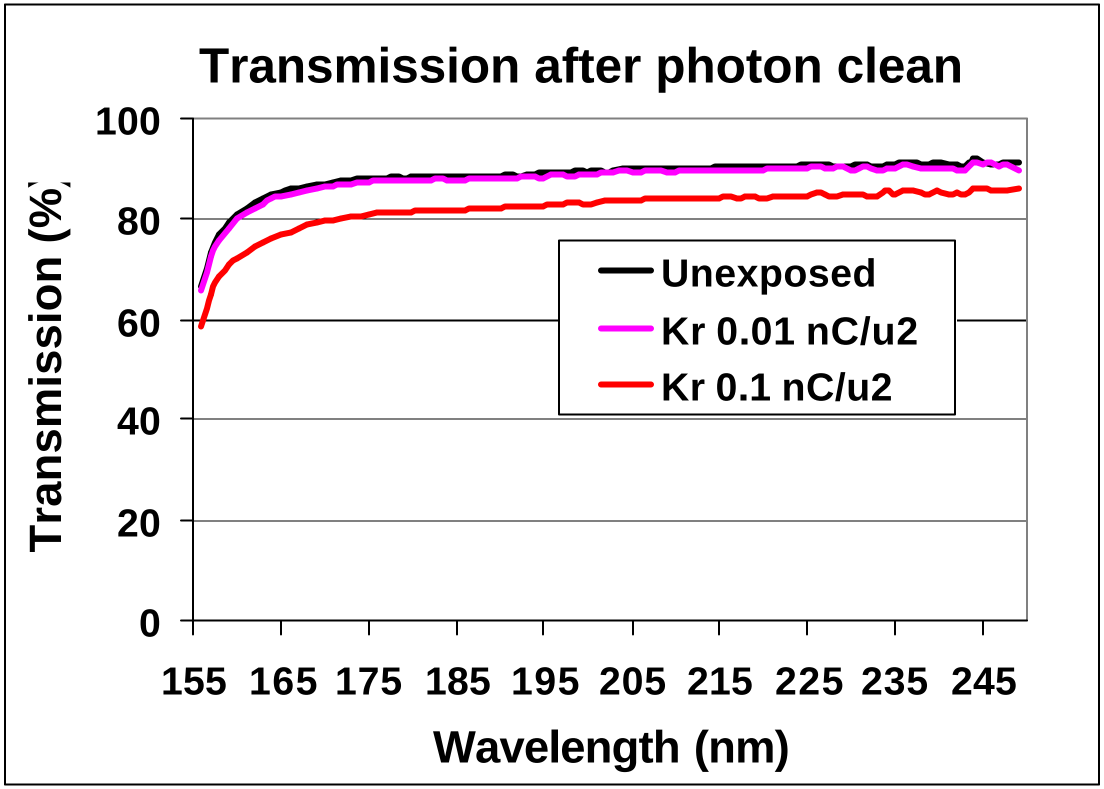
- In the sample compartment:
  - $[O_2] < 0.25$ ppm
  - $[H_2O] < 0.5$ ppm
  - THC < 2 ppb

Ga ion stain results @157nm



- 4.2% transmission loss @ 157nm during defect imaging
- 62% transmission loss @157nm after 0.1nC/μ^2 repair

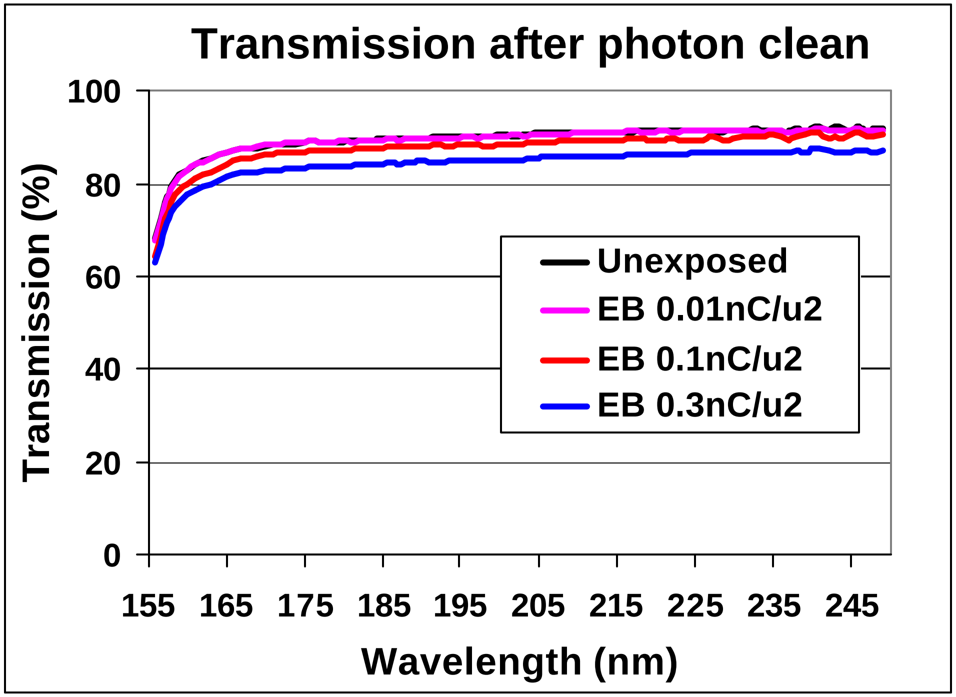
Kr ion stain results @157nm



- 1.2% transmission loss @157nm during defect imaging
- 11% transmission loss @157nm after 0.1nC/μ^2 repair

E-beam stain results

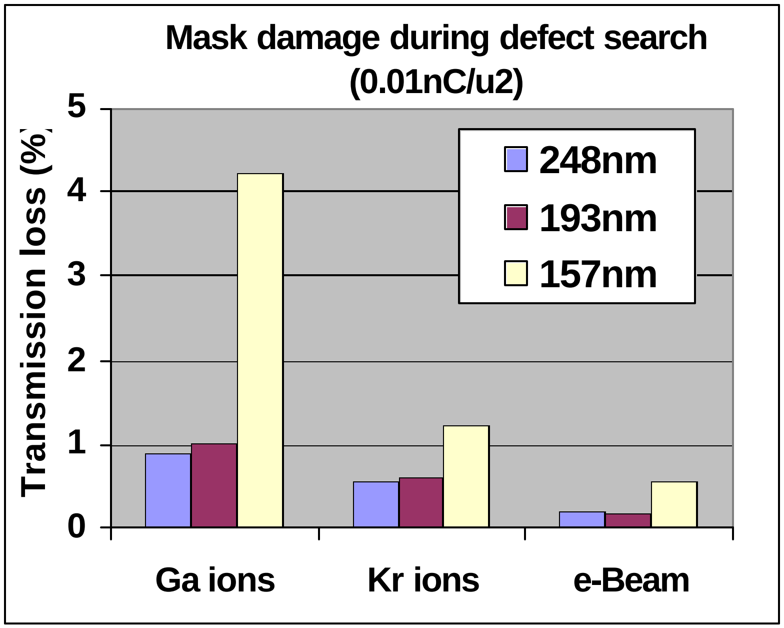
- Advantages of e-beam based repair over the use of ions:
  - Damage-free and pure chemical process – high etch selectivity
  - High spatial resolution

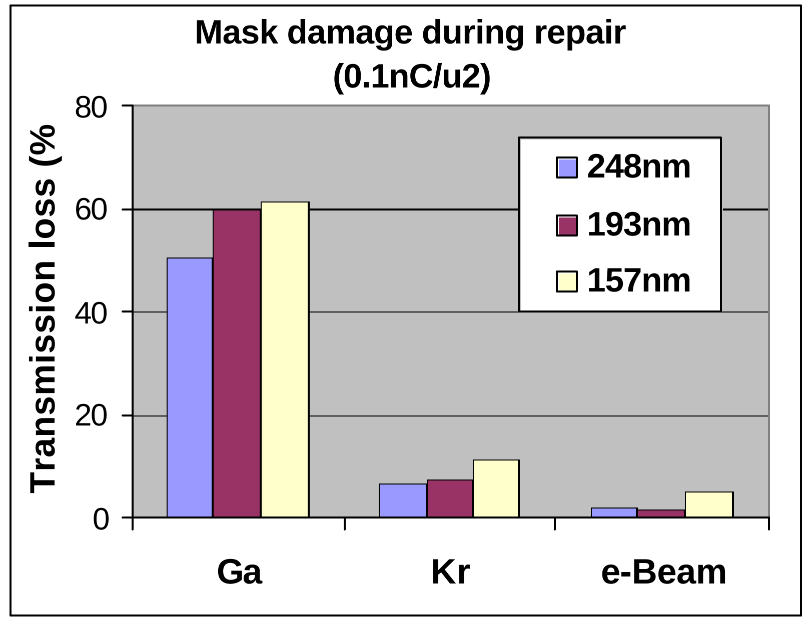


- 0.6% transmission loss @157nm during defect imaging
- 5% transmission loss @157nm after 0.1nC/μ^2 repair

Comparison summary

- In general, transmission loss is more at 157nm



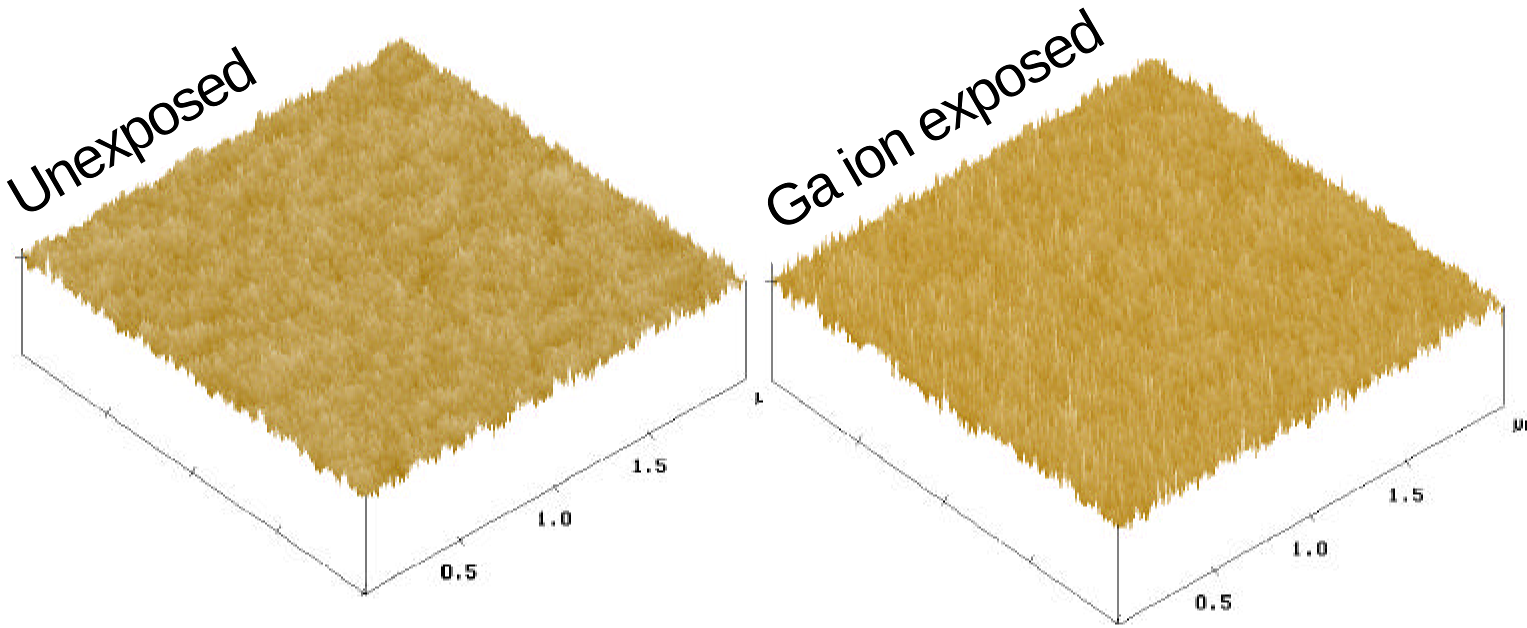


- Possible causes:
  - Ga ion stain
  - Surface damage (increased roughness)
  - Remaining organic contamination after 172nm photon+O2 clean (important at low dose)

Surface roughness

- Exposure did not change surface roughness

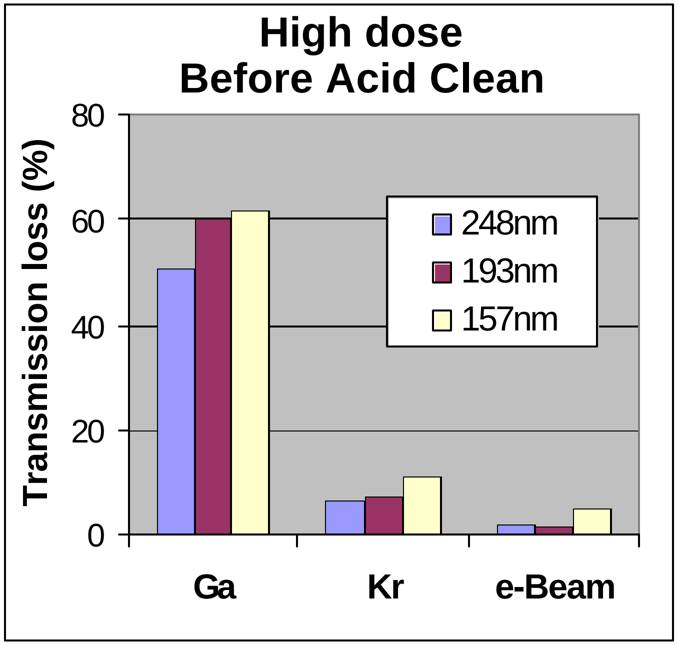
	Un-exposed	Ga ion	Kr ion	e-beam
Range (nm):	2.3	3.3	2.4	2.8
RMS (nm):	0.23	0.28	0.25	0.23

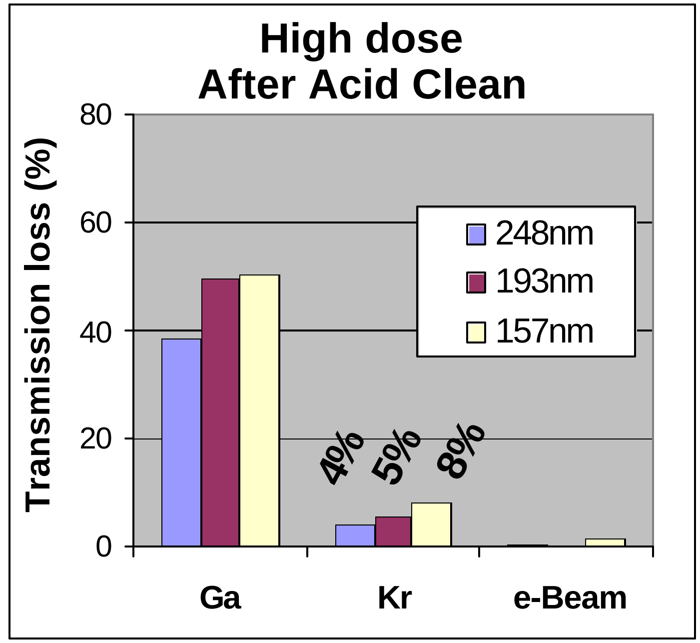


- Surface roughness does not cause transmission loss

Transmission after acid wet clean

- Used H_2SO_4+H_2O_2 acid to clean the exposed substrates





- Transmission loss partially recovered after acid clean:
  - High dose: ~10% transmission recovery
  - Low dose: < 0.5% transmission loss after clean
- Effect is believed to be from organic removal.

Summary

- We evaluated the transmission loss of 157nm mask substrate after exposure to Ga ions, Kr ions and electron beams as measured by spectrophotometer with 250nm spatial resolution.
- Ga ions caused ~10X more transmission loss for the mask substrate compared to Kr ions and e-beam.
- Partial transmission can be recovered by wet acid clean, possibly from the removal of organic contamination remained after photon clean
- Alternative damage-free mask repair using Kr ions or electrons cause minimal damage to the mask substrate.

Acknowledgements: Ron Wu, Tim Pinkerton

Backup foil: Spectrometer layout

- **<u>Top view of spectrometer layout</u>**